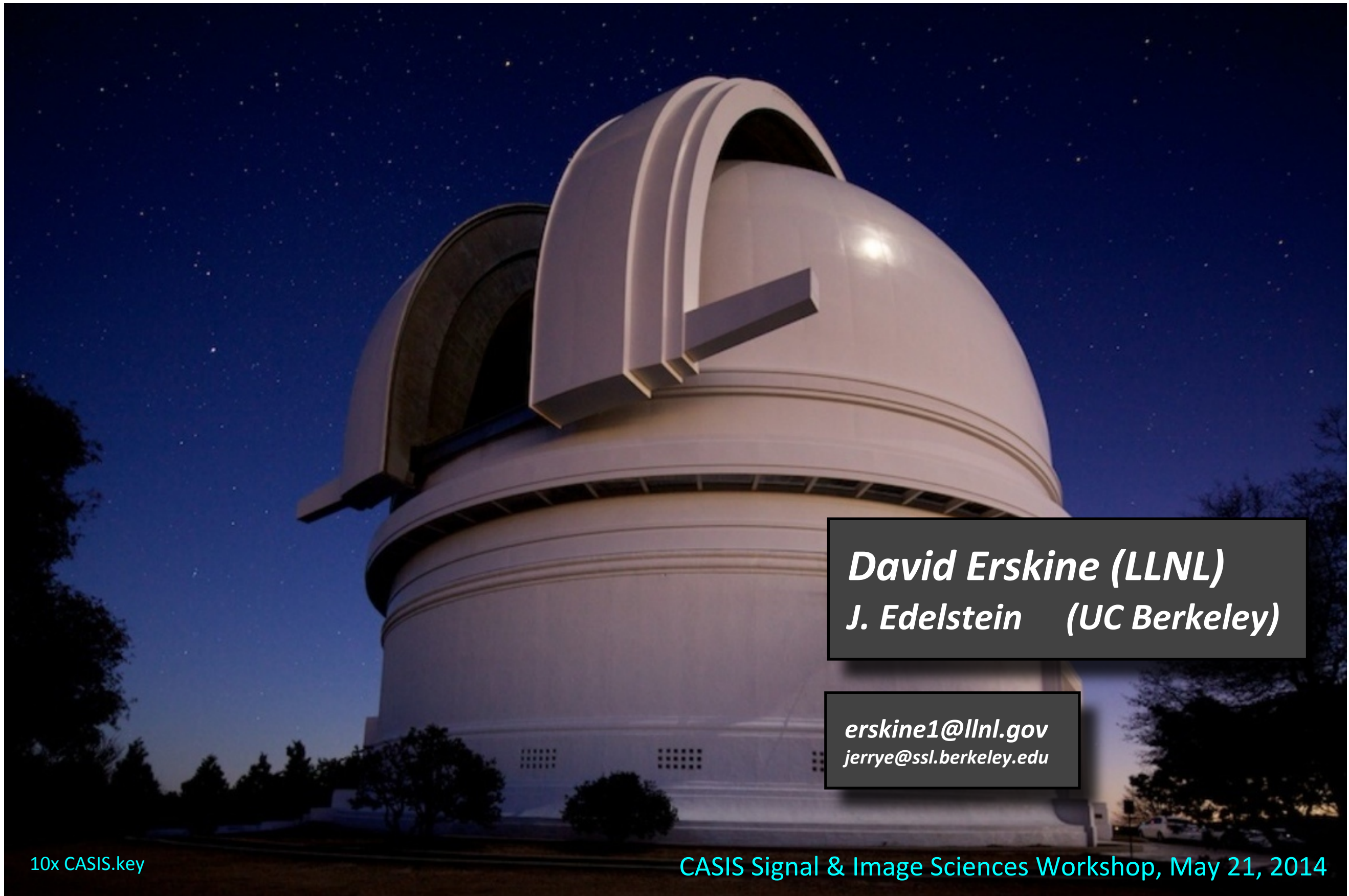


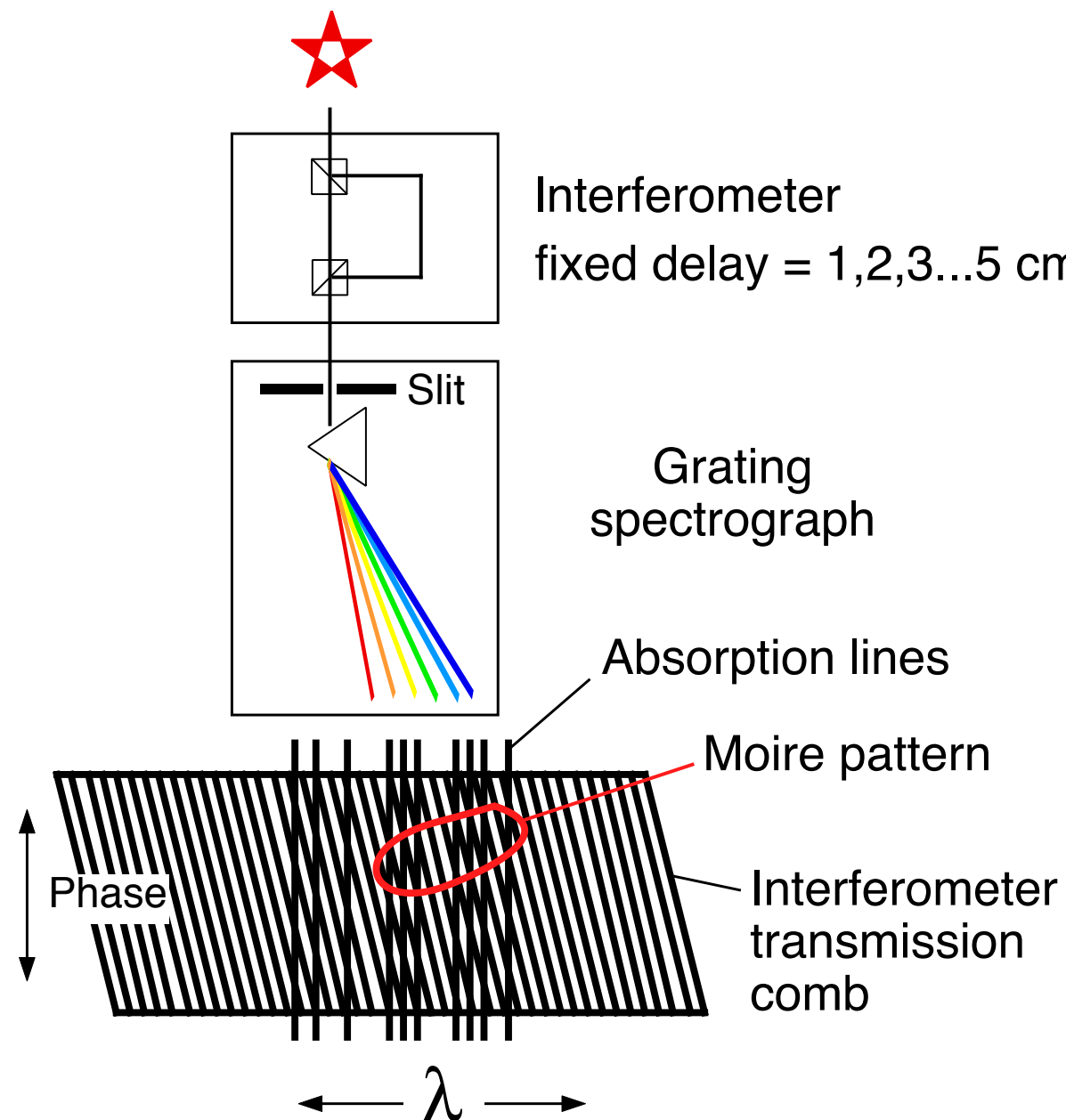
Moire Effect Produces 10x Resolution Boost on Mt. Palomar NIR Spectrograph



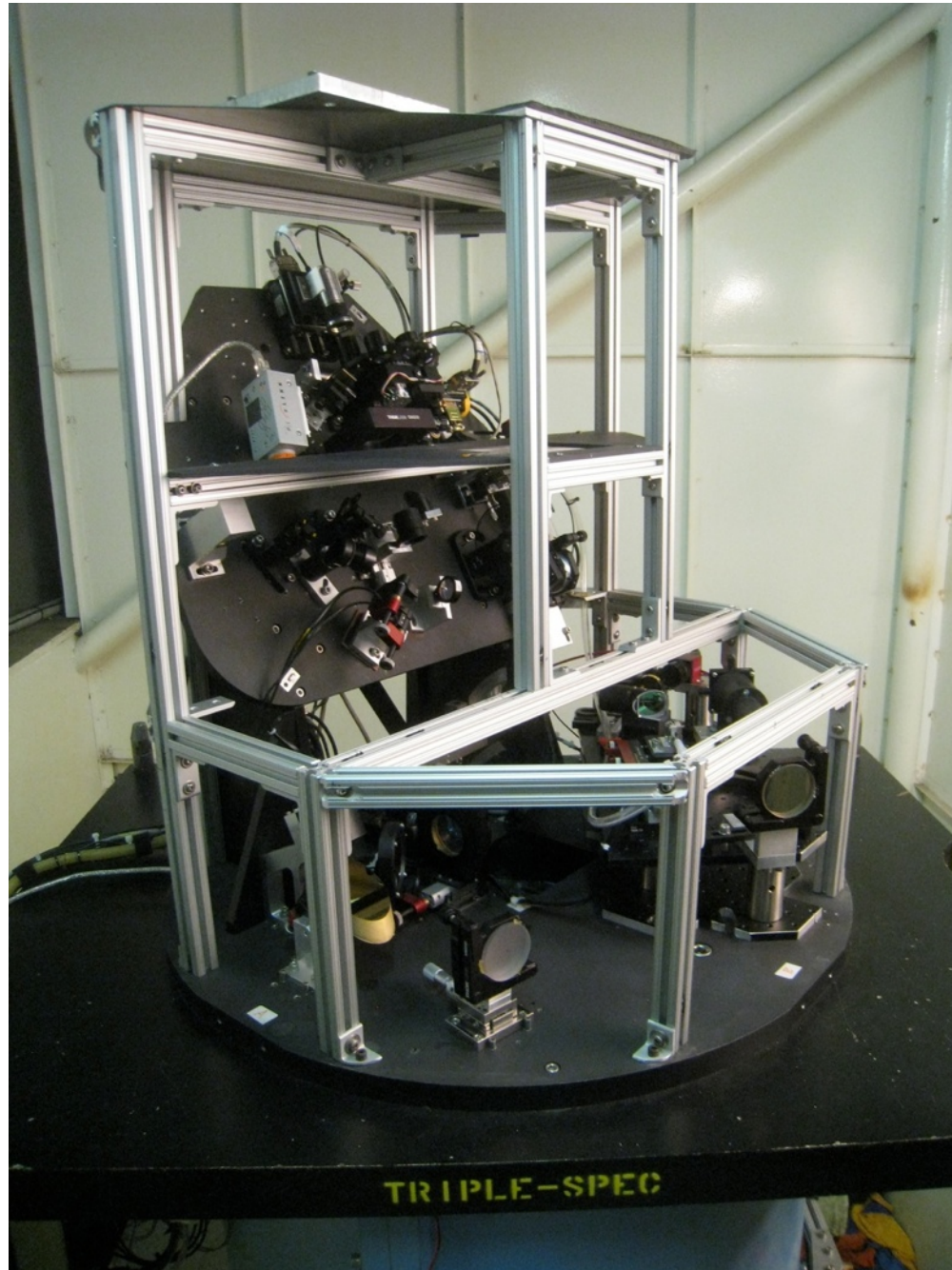
David Erskine (LLNL)
J. Edelstein (UC Berkeley)

erskine1@llnl.gov
jerrye@ssl.berkeley.edu

Externally Dispersed Interferometer Scheme

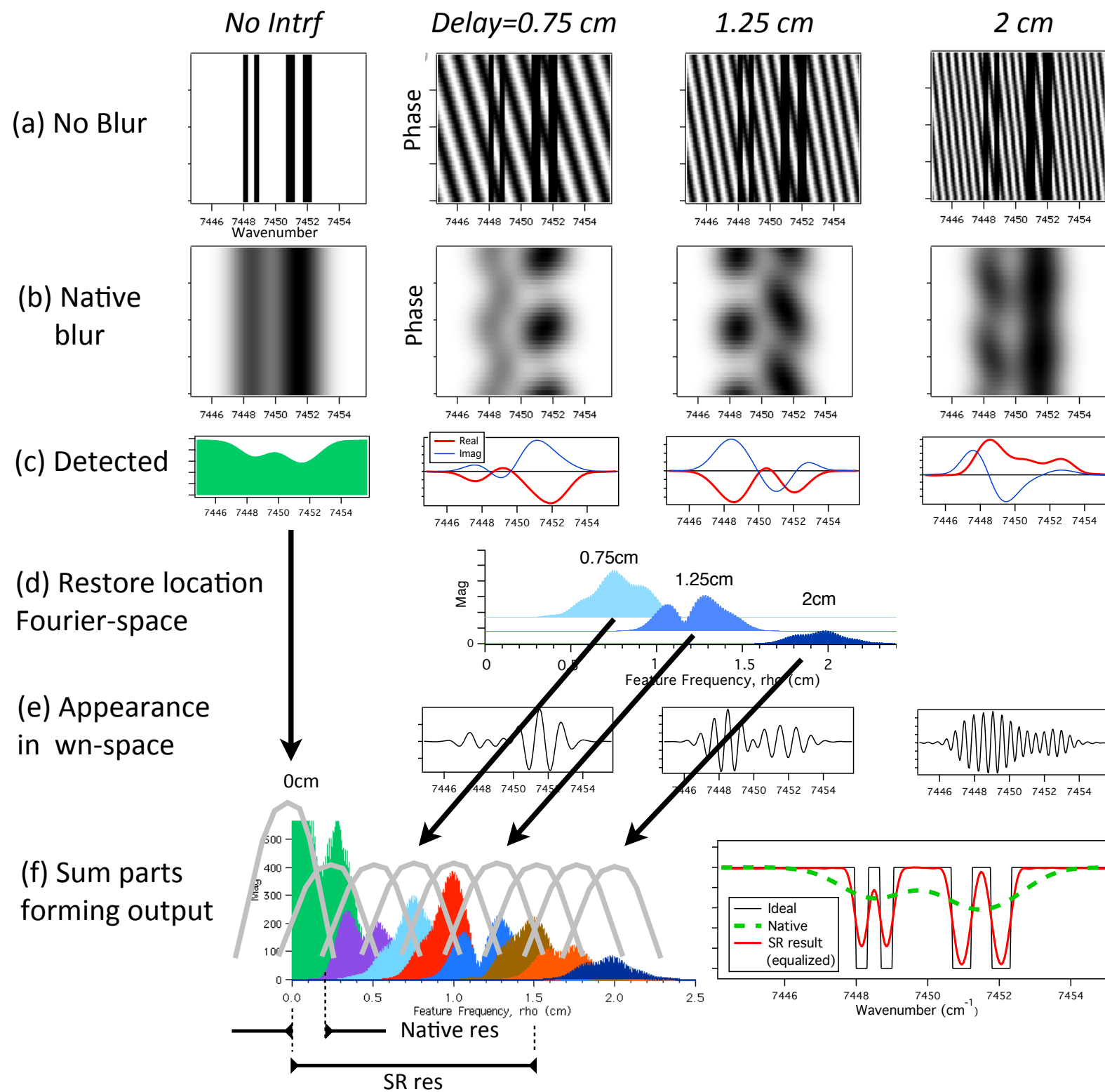


Externally Dispersed Interferometer (EDI) scheme. The sinusoidal transmission comb of the interferometer multiplies the stellar spectrum yielding a moiré pattern. This manifests high resolution spectral information (high feature frequency) heterodyned down to broad and detectable features (low feature frequency). The interferometer delay (optical path difference) is chosen from several fixed values, typically 1 to 5 cm, to sense different feature frequency regions. The overall moiré phase shifts in proportion to target Doppler velocity, and is the subject of other reports.^{1,2} The *shape* of moiré pattern encodes the shape of the high resolution spectrum. The topic of this paper is to reverse the heterodyning process and deduce the original spectrum from a series of moiré patterns measured at different delays.

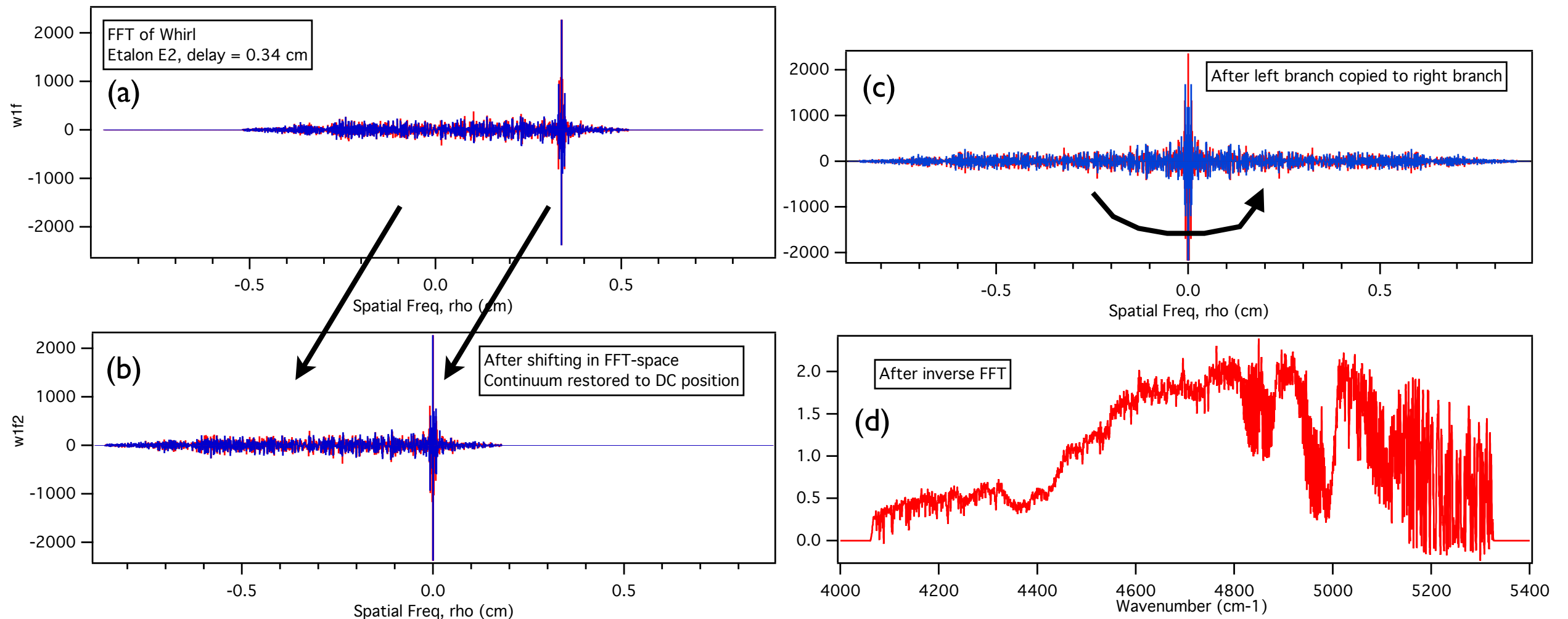


Photograph of the TEDI interferometer, which sits atop Cornell's TripleSpec spectrograph (blue cryogenic cylinder). The interferometer fits in the Cassegrain output cavity of the Mt. Palomar 200 inch mirror, while the TripleSpec is bolted to the bottom of the mirror. The TEDI unit captures the starlight, passes it through an interferometer, and then re-injects it to the spectrograph with a beam having same $f/\#$ and focus location as original beam. (The non-interference spectra displayed in this article are with the arm in place, by summing several fringing exposures to cancel the fringing components.)

Moire Effect

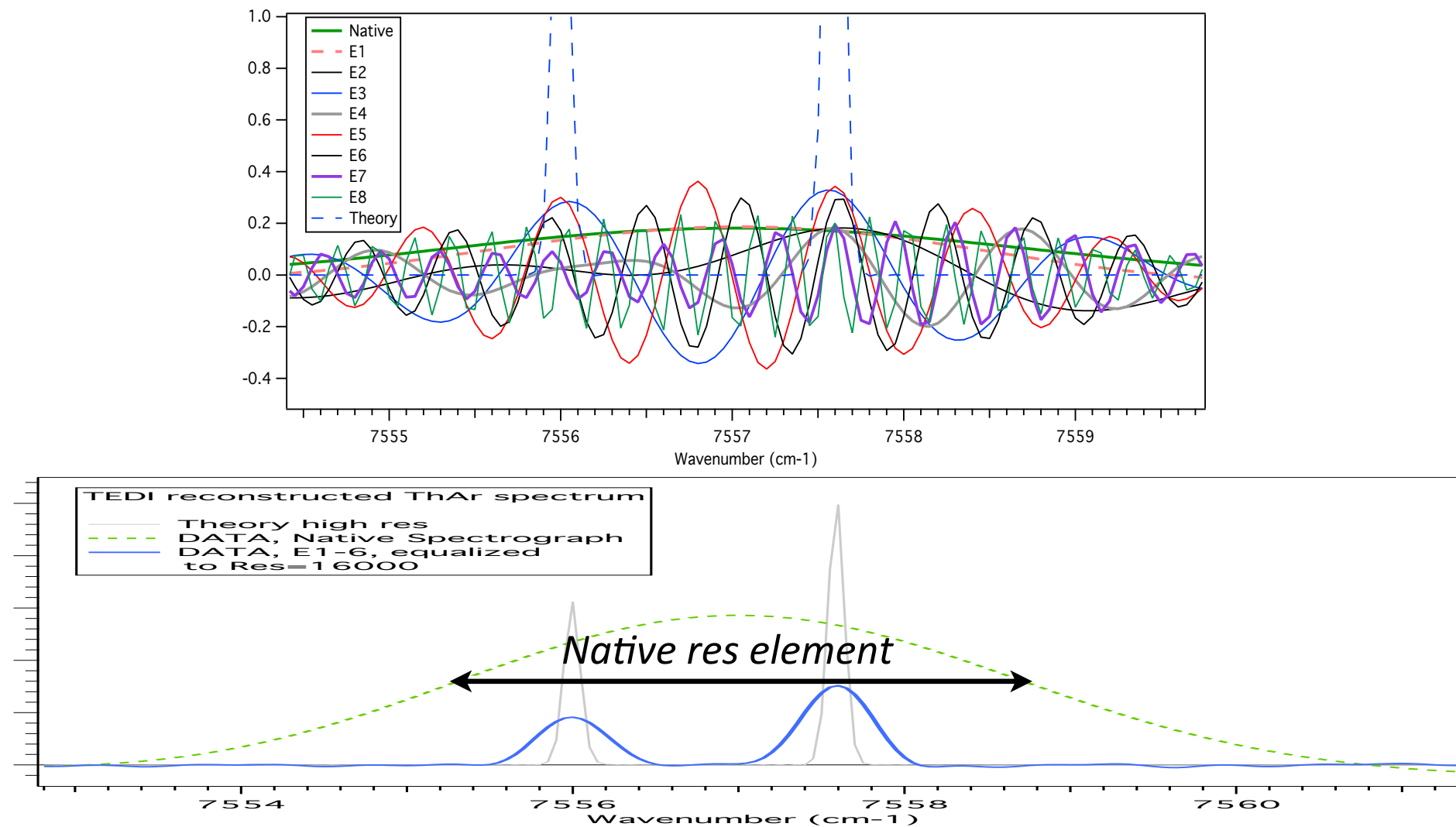


Reverse Heterodyning, Shift in Fourier Space



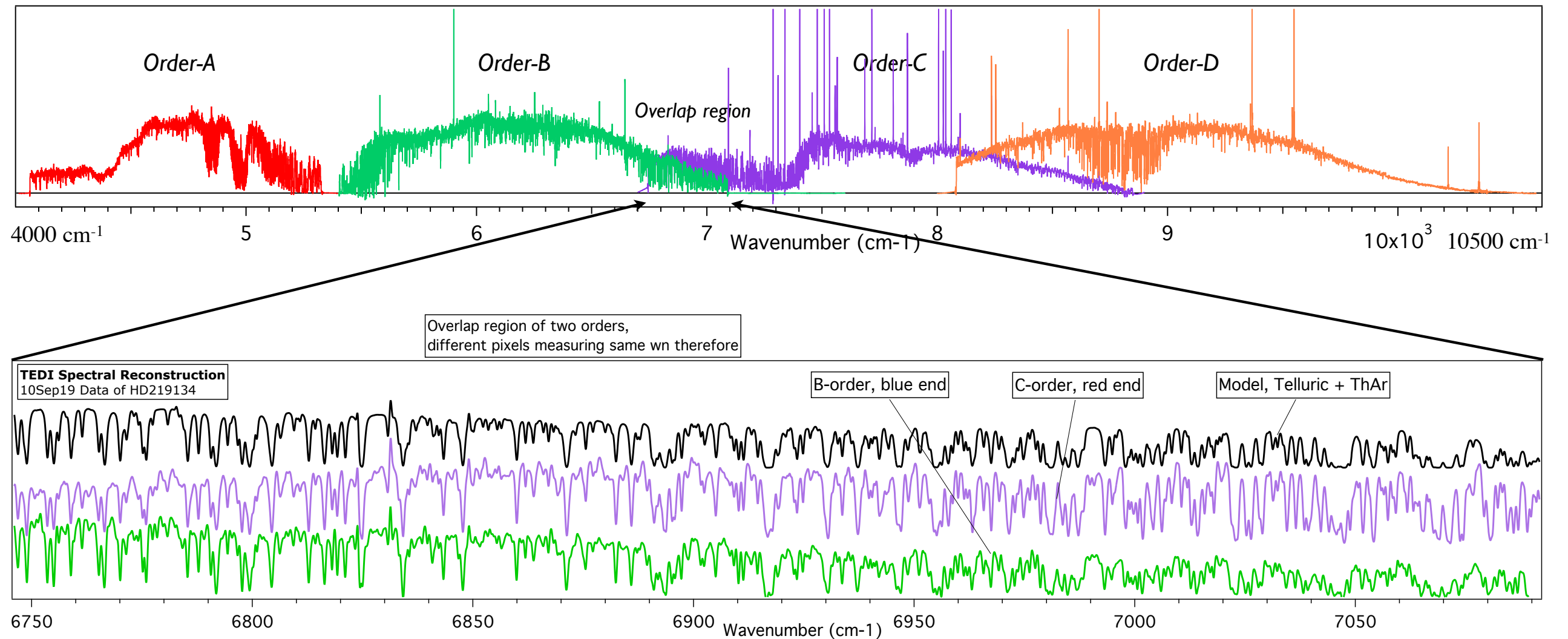
Stages of heterodyning reversal processing. (a) Fourier transform of whirl, here for etalon E2 having small delay of 0.33 cm. This puts continuum comb spike at 0.33 cm, which is within detectable range of native spectrograph ($-0.5 < \rho < 0.5 \text{ cm}^{-1}$). (b) The Fourier transform is shifted by the etalon delay, which moves the comb spike to zero frequency, along with moving other signal energy to left. For larger delay etalons there may be no comb spike and the signal energy ends up even further to the left. (d) The inverse Fourier transform is applied and the imaginary part set to zero to form a purely real output spectrum. This has same effect as (c) adding the complex conjugate to making the right and left frequency branches mirror reflections. Since the E1 and E2 etalons are small enough to produce a resolvable continuum comb, the resulting spectra will have all the information of an ordinary spectrum plus additional higher resolution information. By adding higher delay components, even higher resolution is produced in the composite final spectrum.

Sum the wavelets



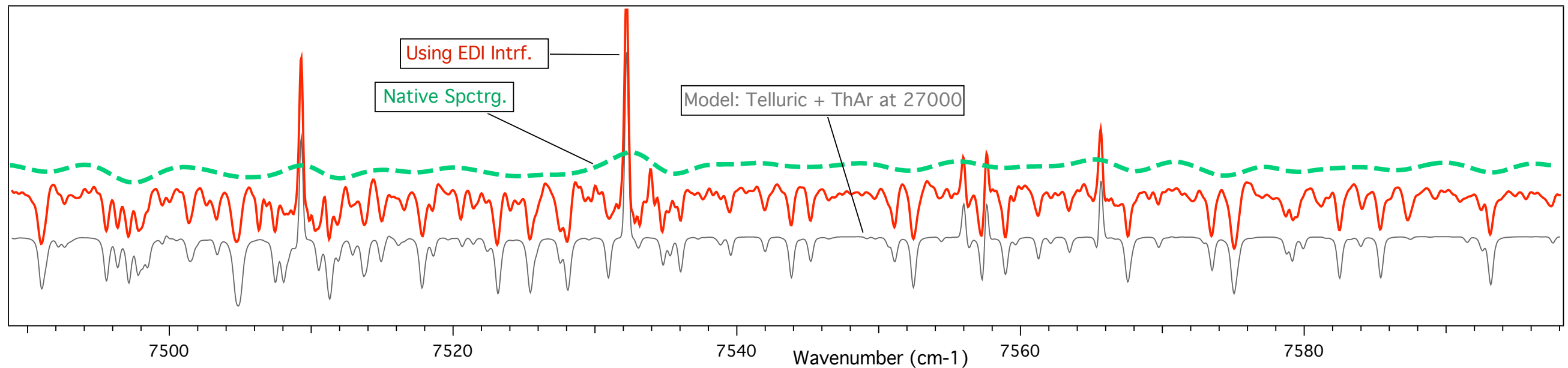
(Top) Reconstruction of an otherwise unresolvable ThAr doublet ($7556, 7557.6 \text{ cm}^{-1}$) from wavelets derived from multiple etalons. (Bottom) Summed results. The native spectrograph (green dash) cannot resolve the doublet (gray, hi res theory). The EDI reconstructed spectrum (solid blue curve) equalized to $\text{res}=16000$ easily resolves the doublet. Since each channel's fringes are produced from the interferometer and not the disperser (except a broad 4 cm^{-1} envelope), the precision of the result is insensitive to the native spectrograph or details of its slit, focal blur, pixel spacing or beamshape.

Unlimited Simultaneous Bandwidth



The TEDI reconstructed resolution boosted spectrum spans the 4 orders of TripleSpec spectrograph in NIR (4100-10500 cm⁻¹), here observing HD219134 on Sept 19, 2010. The lower graph is zoomed in region of overlapping orders B & C, showing agreement between two very unrelated groups of pixels (on opposite sides of detector), and with telluric model¹⁴ (black curve).

10x Resolution Boost on Starlight



Demonstration of a 10-fold resolution boost observing telluric features mixed into spectrum of star κ CrB along with ThAr calibration lamp emission lines. The green dashed (top) curve is the “ordinary” spectrum measured without the interference, having native resolution 2,700. It cannot resolve any of the telluric features. The red (middle) curve is the EDI (TEDI) reconstructed spectrum measured with 7 contiguous delays, up to 3 cm, and equalized to a Gaussian resolution of 27,000. The gray (bottom) curve is a model of telluric¹⁴ and ThAr¹⁵ features blurred to resolution of 27,000, showing excellent agreement with ISR data. Resolution boosting occurs simultaneously across the full bandwidth (0.9-2.45 μm) of the native spectrograph (final resolution varies linearly with wavenumber times largest delay).

The end